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INTRODUCTION

Scope

This guideline provides knowledge on how to design a furnace. This design guideline can assist to understand the basic design of furnace with suitable size, material and heat of combustion. A furnace is one of the most important pieces of equipment in a process plant. Furnace firing provides a large part of the heat for the process. The heat for the process comes from the combustion of fuels.

The choice of furnace style and design is crucial for the best performance of furnace. Factors affecting the performance of furnace are influenced by the maximum the heat absorbed, the capacity of burners, process requirements, economics and safety.

The theory section explains the selection of the furnace type, calculation of sizing, heat transfer concepts and combustion basics. The application of the furnace theory with the examples assists the user to study the furnace concepts and be prepared to perform the actual design of the furnace.

General Design Consideration

Heat is one of most important things in the process plant industry. Equipment that produces and supplies the heat requirement to process plant is called a furnace. Furnaces have high temperatures, open flames, oxygen and fuel; all the components of combustion.

The term furnace can also refer to a direct fired heater. They expose hydrocarbon stream to heat that drives a distillation tower, a reactor, and in some cases, change the stream's molecular structure through cracking.

Basically furnace has four basic components, consisting of box, burner, coil, and stack. The burner will produce the heat then the heat liberated by the combustion of fuel is transfer to a process fluid flowing through tubular coils. In this below are several types of furnace:

1. Vertical cylindrical fired heater

This furnace is commonly used in hot oil service and other processes where the duties are usually small. These heaters are probably the most common in use today and are used for heat duties up to about 150 MBtu/hr. This type of cylindrical upright, tube in the radiant section mounted vertically in a circle round of the burner. The burner is located on the bottom floor, so that the flame is parallel with the tube. Fire heater of this type can be design without or with convection section. Below is kinds of the cross section of vertical-cylindrical fired heater.

a. **Vertical cylindrical all radiant**:

The all-radiant heater is inexpensive, but since the temperature of flue gases leaving the heater is high, 1500 – 1800oF . Heater of this type does not have convection section. Usually this type have low efficiency and heat duty ranges from 3-7 million kcal/hour.

b. **Vertical cylindrical helical coil**:

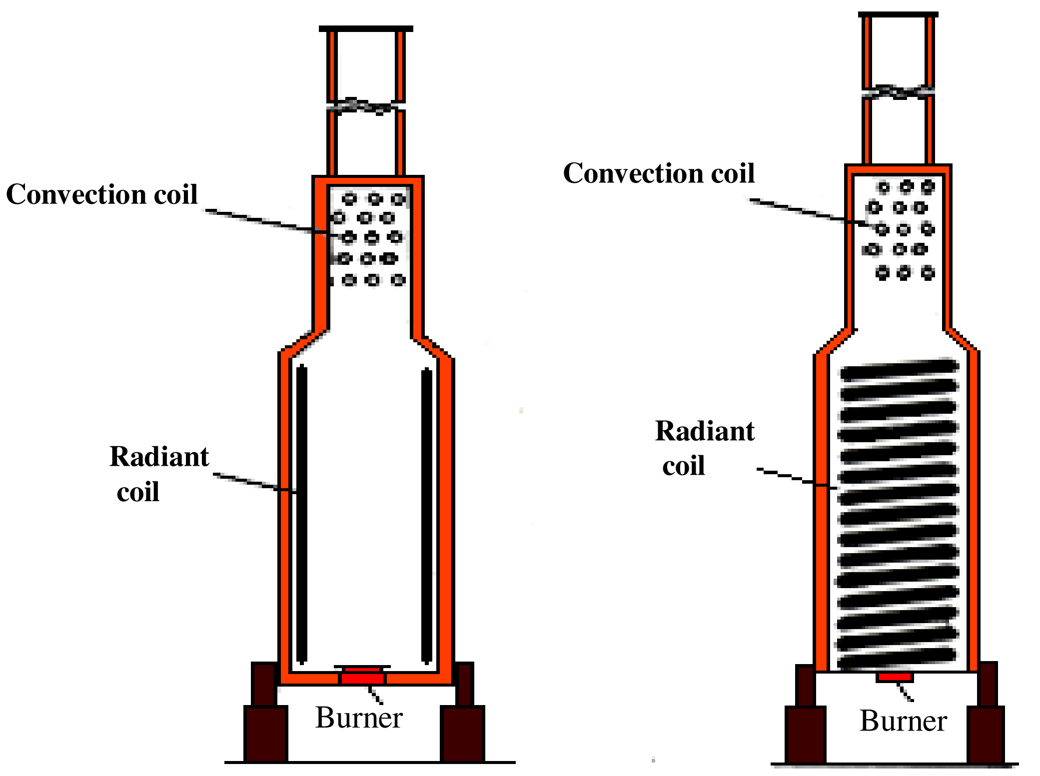
The coil is arranged helically along the cylindrical wall of the combustion chamber. Its primary use is to heat thermal fluids and natural gas. Capacities range from 1 to 30 million Btu/hour.

c. **Vertical cylindrical with crossflow convection section**:

The convection section is installed above the combustion chamber. Mostly, air preheater are added to increase the efficiency. Heat duty of this type from 5-35 million kcal/hour.

d. **Vertical cylindrical with integral convection**:

The distinguishing feature of this type is the use of added surface area on the upper part of the radiant coil to promote convection heating. This type is added surface area on the upper part of the radiant coil to promote convection heating. Duties are from 2.5 – 25 million kcal /hr.



(a) (b)

Figure 1: Vertical cylindrical fired heater: (a) all radiant and (b) helical coil

2. Horizontal tube cabin fired heaters

This cabin has room type consists of the radiation and convection. Tube-tube mounted horizontally while the burner is located on the floor furnace, so that the flame is not straight and parallel to the wall heater. The first layer of tubes in the convection section directly facing into combustion chamber or the radiant fire box called shield tubes. The burner mounted on the floor of the cabin and fire is directed vertically.

Cabin fired heater have some variation in the application. It is like cabin furnace with a centre wall. In the figure below the fire heater usually can be used for the large fired heater and has two separate heating zones are required in the radiant section. This design is economical, high efficiency duties are from 20 - 50 million kcal/hour. In many operations, about 75% of the heat is absorbed in the radiant zone of a fired heater.

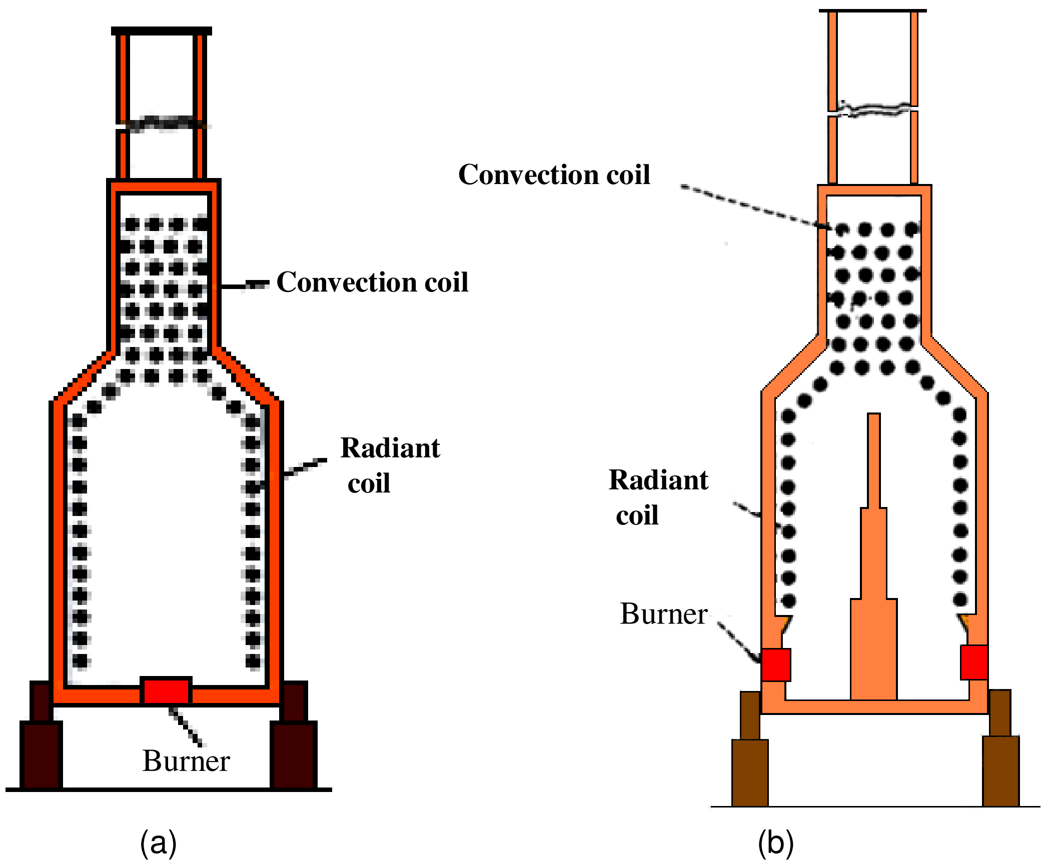


Figure 2: Horizontal tube cabin fired heaters: (a) cabin with convection section and (b) cabin with dividing bridge wall

3. Hoop-tube fired heater

This fire heater has tube bent like U-type with vertically oriented. In all-vapor flow, non-coking services where low coil pressure drop is desired. This design is used where the pressure drop must be very low since the path through each tube provides a design with many passes. Application of this type is in the catalytic reformers charge heater. Duties are from 13-25 million kcal/hr.

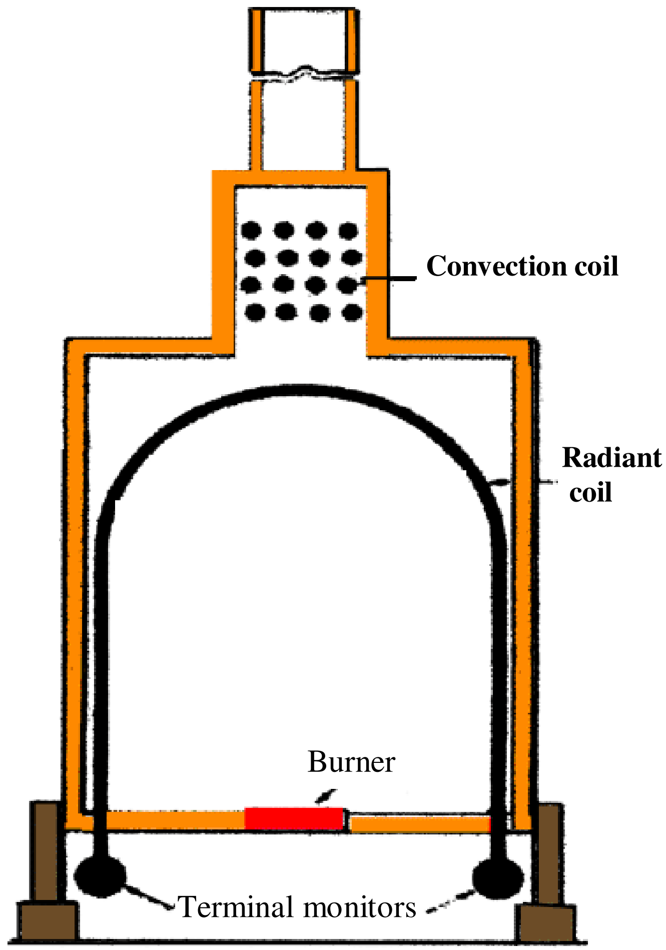


Figure 3:. Hoop-tube fired heater

4. Vertical tube box fired heaters

In this fire heater, tubes stand vertically along wall in the radiant section. Vertical radiant tubes are arranged in a single row in each combustion cell (there are often two cells) and are fired from both sides of the row. Such an arrangement yields a uniform distribution of heat-transfer rates about the tube circumference. This heater is suitable for the large forced-draft burners. Requirement of heat input to each cell provided by burner.

5. Horizontal tube box fired heaters

The radiant and convection section in a typical of horizontal tube box in the **Figure 5** are separate by a wall called bridge wall. Function of bridge wall is to create a good direction of flame and to stream the smoke in to flue stack. Burners are firing from the floor along both sides of the bridge wall. Duties are from 30 to 8 million kcal /hour.

6. Multiple cell heaters

For two-cell horizontal tube box have high efficiency, duties from 25-65 million kcal/hour.

7. Helical coil fired heater

This heater configuration is commonly used where the duties are small. Since each pass consists of a separate winding of the coil, pressure drop options are limited. Many of these only have a radiant section, since efficiency is often not that critical, especially in intermittent services like for a regeneration heater.

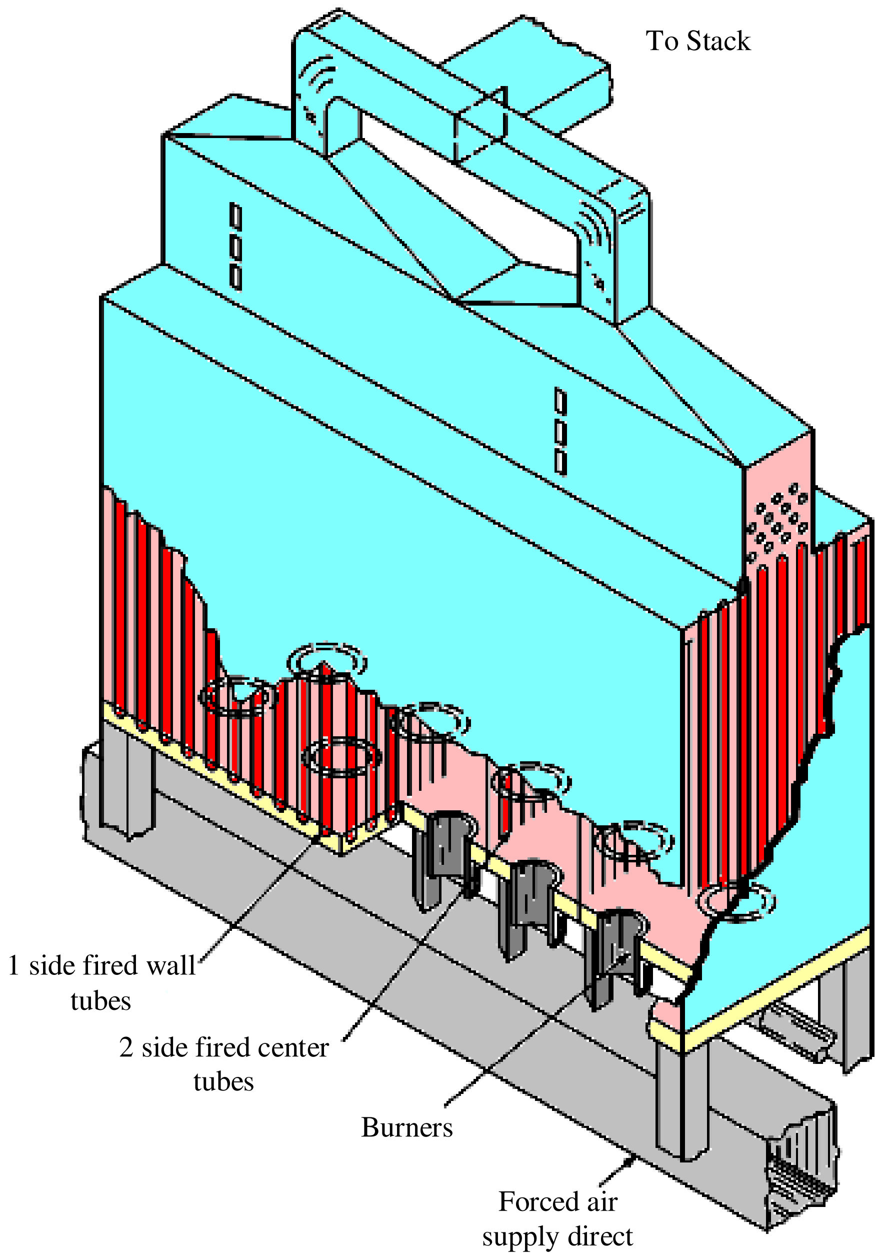


Figure 4: Vertical tube box fired heaters

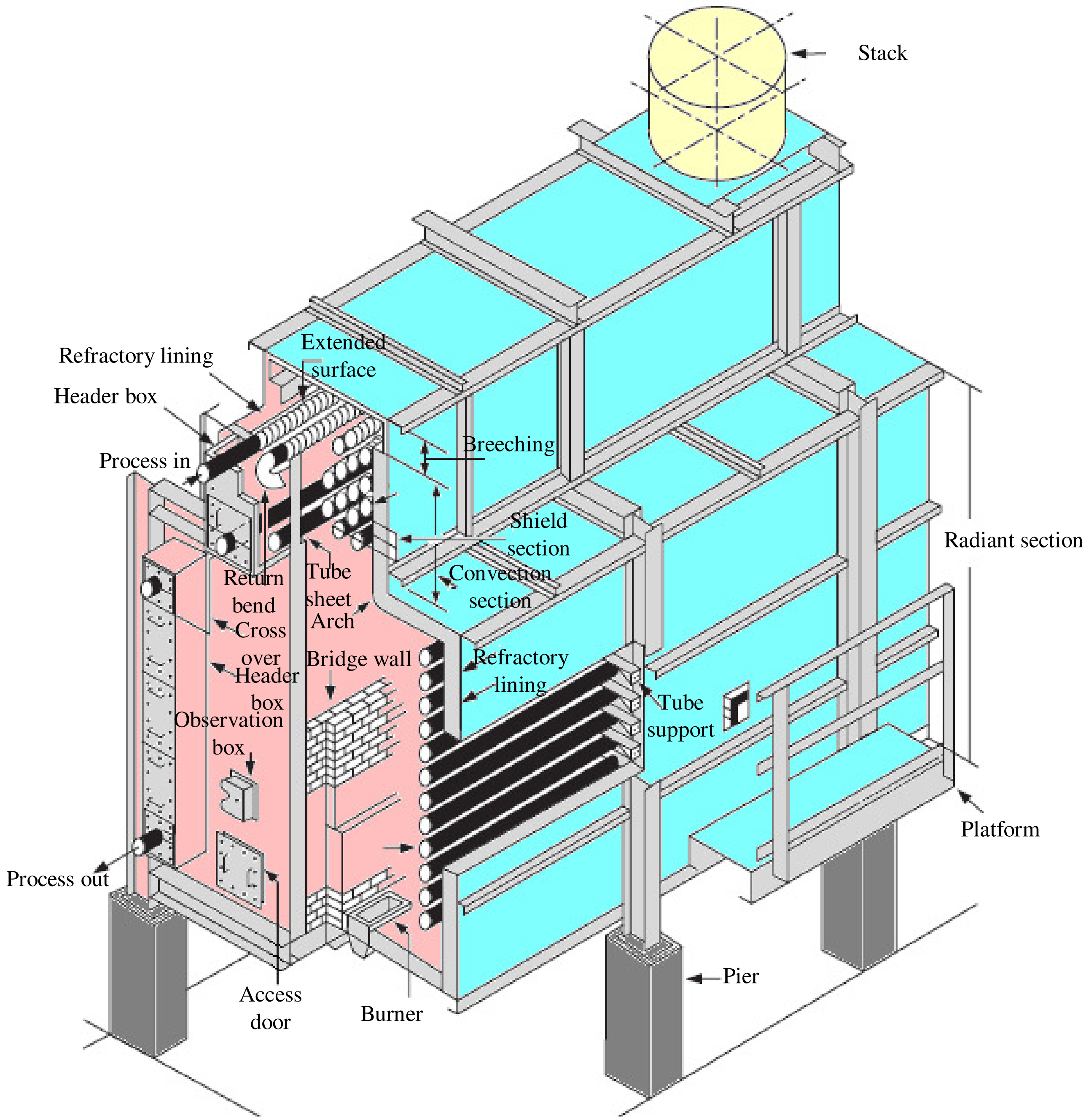


Figure 5: Horizontal tube box fired heaters

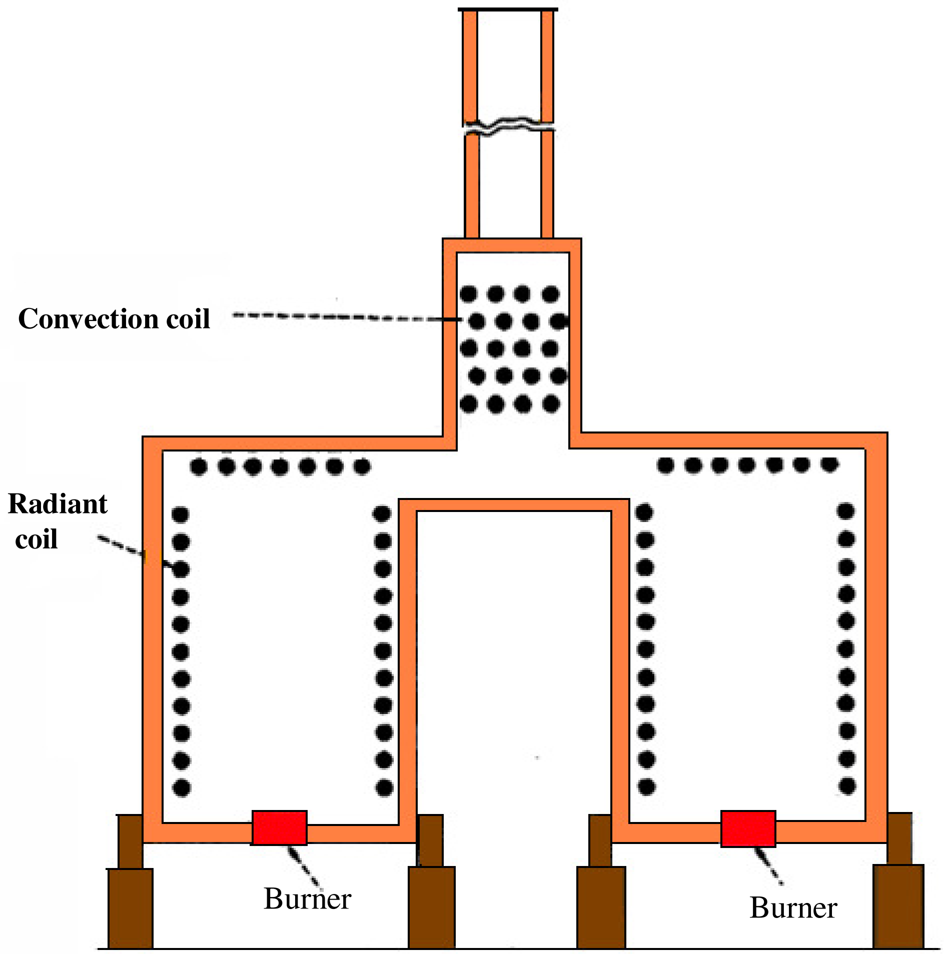


Figure 6: Multiple cell heaters

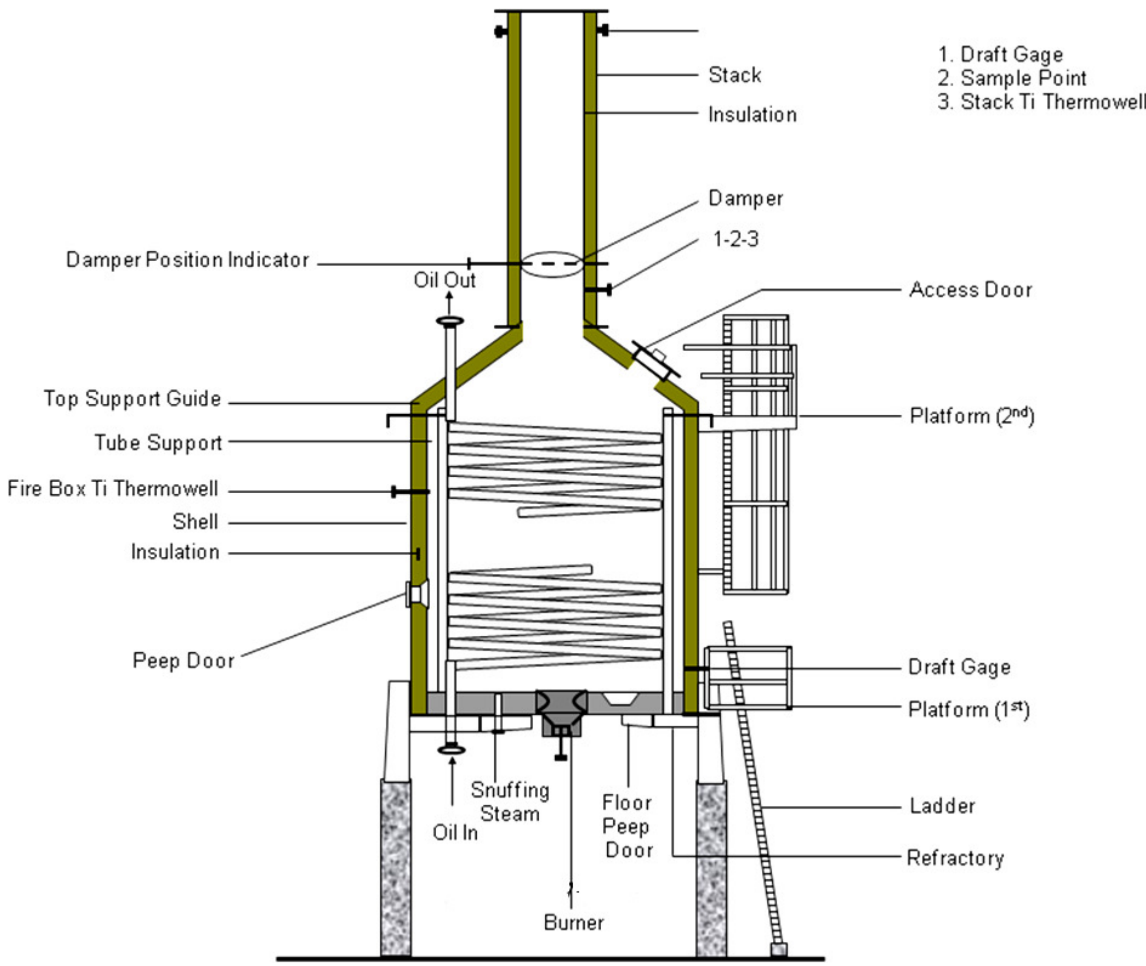


Figure 7: Helical coil fired heater

A Fired heater will work well if designed properly. The design requirements must be properly addressed. Fired heater performance can be measured by a combination of operability and maintenance.

There are several factors effecting fired heater selection and design: all-liquid vaporizing service and all-vapor service.

1. Fire heaters in all-liquid or vaporizing service

   Inside the tube wall coke may be formed that can interfere with heat transfer process. Fired heaters should be design to minimize coke. Incipient coke begins to form at a film temperature above about 660oF, usually equivalent to a bulk fluid temperature of about 600oF. In other services such as visbreaking and thermal cracking, where fluid cracking is an inherent characteristic of the process, acceptable coke formation and run length can usually be attained if film temperatures do not exceed 910^{o}F equivalent to a bulk fluid temperature of about 880^{o}F.

   For reduce the formation of coke, a high inside film coefficient is necessary to minimize the difference between bulk fluid and film temperature. The higher the speed of the mass of the heat transfer coefficient will be better. Therefore, the mass of turbulent flow must be maintaining in the tube.

2. Fire heater in all-vapor service

   For this fired heater service is generally not as susceptible to the severe coking problems as those in vaporizing services because of the lighter nature of the process fluid.

To achieve the lowest possible utility cost, a furnace must operate at maximum efficiency. When a furnace is operated properly, the furnace and its parts have a longer working life with minimum repairs. A properly run furnace is a safe furnace. Skillful handing of a furnace means safety for worker.

Heat is produce by the ignition of fuel at the burner in the firebox. The tubes along the wall of the firebox are the radiant and the shock bank tubes. These tubes receive radiant heat from the burners. The firebox wall and roof is lined with a material then reduce heat losses and radiates heat back to the tubes. The entire furnace structure must be air tight for efficient furnace operation. Air should only enter at designed entries. An air leak reduces the efficiency of the furnace. Below are design considerations for furnace.

1. Heaters shall be designed for uniform heat distribution
2. Multi-pass heaters shall be designed for hydraulic and thermal symmetry of all passes. The number of passes shall be minimized. Each pass shall be a single circuit
3. Average heat flux density in the radiant section is normally based on single row of tubes with two nominal tube diameter spacing.
4. The maximum allowable inside film temperature for any process service shall not be exceeded in the radiant, shield, or convection sections.
5. minimum radiation loss 2.5 % the total heat input
6. Natural draft needs 25% excess air when oil is the primary fuel and 20 % excess air when fuel gas is the primary fuel. In case of forced draft operation, 20% Excess air for fuel oil and 15% Excess air for fuel gas
7. Heaters shall be designed such that a negative pressure of at least 0.10 inches of water (0.025 kilopascals) is maintained in the radiant and convection sections at maximum heat release with design excess air.
8. The flue gas dew point can be predicted, and the minimum tube-metal temperature can be kept high enough to prevent condensation, if the fuel's sulfur content has been correctly stated. (For estimated flue gas dew points with respect to sulfur content in fuel oil and gas
9. In a well-design heater, the radiant-section heat duty should represent more than 60% to 70% of the total heat duty
10. The bridge wall temperature should range between 800°C to 1,000°C.

11. Higher radiant flux means less heat transfer surface area for a given heat duty; hence, a smaller furnace.
12. The higher the film temperature, the greater is the tendency of the fluid (particularly a hydrocarbon) to crack and deposit a layer of coke.
13. Heat-transfer fluids tend to degrade quickly at high film temperatures.
14. The coke layer acts as an insulator, retarding heat transfer, which could cause tube overheating and lead to tube failure.
15. Also, a heavy coke deposit can restrict the flow through the coil, lowering the inside heat transfer coefficient and further increasing the tube wall temperature.
16. The smallest firebox for a certain duty will obviously produce the cheapest design.
17. The flame impingement and consequent tube failure that could result can be avoided by specifying a minimum safe distance between burners and tubes, based on experience

Followings are the mechanical design for furnace and these will be discussed a much deeper in theory section.

1. Provision for thermal expansion shall take into consideration all specified operating conditions, including short term conditions such as steam-air decoking.
2. The convection section tube layout shall include space for future installation of soot-blowers or steam lancing doors.
3. The convection section shall incorporate space for future addition of two rows of tubes.
4. When the heater is designed for fuel oil firing, soot-blowers shall be provided for convection section cleaning.
5. Vertical cylindrical heaters shall be designed with maximum height to diameter ratio of 2.75, where the height is the radiant section height and the tube circle diameter.
6. Shield sections shall have at least three rows of bare tubes.
7. Convection sections shall be designed to minimize flue gas bypass. Baffles may be employed.
8. The minimum clearance from grade to burner plenum or register shall be 6 feet 6 inches (2.0 meters) for floor fired heaters.

9. For vertical cylindrical heaters, the maximum radiant straight tube length shall be 60 feet (18.3 meters).
10. For horizontal heaters fired from both ends, the maximum radiation straight tube length shall be 40 feet (12.2 meters).
11. Radiant tubes shall be installed with minimum spacing from refractory or insulation to tube centerline of one and one half nominal tube diameters, with a clearance of not less than 4 inches (10 centimeters) from the refractory or insulation.
12. For horizontal radiant tubes, the minimum clearance from floor refractory to tube outside diameter shall be not less than 12 inches (30 centimeters).
13. The heater arrangement shall allow for replacement of individual tubes without disturbing adjacent tubes.

DEFINITIONS

Air Preheater - Heat exchanger device that uses some of the heat in the flue gases to raise the temperature of the air supply to the burners.

Breeching - The hood that collects the flue gas at the convection section exit.

Bridgewall Temperature - The temperature of the flue gas leaving the radiant section

Bulk Temperature - The average temperature of the process fluid at any tube cross section.

Center Wall - A refractory wall in the radiant section, which divides it into two separate cells.

Coil - A series of straight tube lengths connected by 180^o return bends, forming a continuous path through which the process fluid passes and is heated.

Convection Section - The portion of a heater, consisting of a bank of tubes, which receives heat from the hot flue gases, mainly by convection.

Corbelling - Narrow ledges extending from the convection section side walls to prevent flue gas from flowing preferentially up the side of the convection section, between the wall and the nearest tubes.

Crossover - Piping which transfers the process fluid either externally or internally from one section of the heater to another.

Damper - A device to regulate flow of gas through a stack or duct and to control draft in a heater.

Draft - The negative pressure (vacuum) at a given point inside the heater, usually expressed in inches of water.

Excess Air - The percentage of air in the heater in excess of the stoichiometric amount required for combustion.

Extended Surface - Surface added to the outside of bare tubes in the convection section to provide more heat transfer area.

Film - A thin fluid layer adjacent to a pipe wall that remains in laminar flow, even when the bulk flow is turbulent.

Film Temperature - The maximum temperature in the film, at the tube wall.

Fire Box - A term used to describe the structure which surrounds the radiant coils and into which the burners protrude.

Flue Gas - A mixture of gaseous products resulting from combustion of the fuel.

Fouling - The building up of a film of dirt, ash, soot or coke on heat transfer surfaces, resulting in increased resistance to heat flow.

Forced Draft - Use of a fan to supply combustion air to the burners and to overcome the pressure drop through the burners.

Fired Heater Efficiency - The ratio of heat absorbed to heat fired, on a lower heating value basis.

Header Box - The compartment at the end of the convection section where the headers are located.

Heat Available - The heat absorbed from the products of combustion (flue gas) as they are cooled from the flame temperature to a given flue gas temperature.

Heat Density - The rate of heat transfer per unit area to a tube, usually based on total outside surface area.

Heat Duty - The total heat absorbed by the process fluid, usually expressed in MBtu/hr

Induced Draft - Use of a fan to provide the additional draft required over that supplied by the stack, to draw the flue gas through the convection section, and any downstream heat recovery equipment.

Lower Heating Value (LHV) - The theoretical heat of combustion of a fuel, when no credit is taken for the heat of condensation of water in the flue gas.

Mass Velocity - The mass flow rate per unit of flow area through the coil. Typical units are lb/s-sq. ft.

Natural Draft - System in which the draft required to move combustion air into the heater and flue gas through the heater and out the stack is provided by stack effect alone.

Net Fuel - The fuel that would be required in the heater if there were no radiation losses.

One-Side Fired Tubes - Radiant section tubes located adjacent to a heater wall have only one side directly exposed to a burner flame. Radiation to the back side of the tubes is by reflection/ re-radiation from the refractory wall.

Pass - A coil that transports the process fluid from fired heater inlet to outlet.

Radiant Section - The section of the fired heater in which heat is transferred to the heater tubes primarily by radiation from high-temperature flue gas.

Service Factor – A measure of the continuity of operation, generally expressed as the ratio of total running days for a given time period to the total calendar days in the period.

Shield Section - The first two tube rows of the convection section.

Sootblower - A steam lance (usually movable) in the convection section for blowing soot and ash from the tubes using high-pressure steam.

Stack - A cylindrical steel, concrete or brick shell which carries flue gas to the atmosphere and provides necessary draft.

Stack Effect - The difference between the weight of a column of high-temperature gases inside the heater and/or stack and the weight of an equivalent column of external air, usually expressed in inches of water per foot of height.

Stack Temperature - The temperature of the flue gas as it leaves the convection section, or air preheater directly upstream of the stack.

Two-Side Fired Tubes - Radiant section tubes which are exposed on both sides to direct radiation from the burners.

NOMENCLATURES

A_{cp}	Cold plane area, (ft^2)
A_{shield}	Tube shield area, (ft^2)
A_{shield}	Tube shield area, (ft^2)
A_w	Refractory surface (ft^2)
A_{tube}	Area of tube, (ft^2)
A_{rl}	Right and left area (ft)
A_w	Refractory surface (ft^2)
A_r	Radiant surface area (ft^2)
C	Capacity design (btu/hr)
E_{ff}	Efficiency of furnace
F	Exchange factor
G_f	Flue gas rate, (lb/hr)
G	Flue gas flow rate (lb/sec ft2)
H	Shell height (ft)
H_{wall}	Wall height (ft)
$H_{persection}$	Height per section (in)
H_{CS}	Height of convection section (in)
L	Shell length (ft)
L_{bm}	Mean beam length (ft)
L_{bft}	The total length of bare of finned tubes, (ft)
L_{exp}	Exposed length (ft)
N_{burner}	The number of burner
N_{tr}	Number of tube in radiant section,

N_r	Amount of radiant section
N_{ts}	Number of tube in shield area,
N_{tc}	Number of tube in ceiling area,
N_{trl}	Number of tube in right and left area,
$N_{tchamber}$	Number of tube in 1 chamber,
N_{ts}	Number of tube in shield area,
N_{tc}	Number of tube in ceiling area,
N_{trl}	Number of tube in right and left area,
$N_{tchamber}$	Number of tube in 1 chamber,
$N_{bsection}$	Number of radiant burner per section
N_{tr}	Number of tube in radiant section
$N_{t1\ section}$	Number of tube in 1 section
OD	Outside tube diameter (in)
P	Partial pressure of CO2 and H2O (atm)
Q_a	Heat absorbed (btu/hr)
Q_{rfc}	Radiant heat flux (btu/hr ft^2)
Q_{rac}	Radiant heat absorbed calculated (btu/hr)
Q_n	Heat released (btu/lb)
Q_a	Heat absorbed needed (btu/hr)
Q_{ra}	Radiant heat absorption (btu/hr)
Q_{rf}	Radiant heat flux (btu/hr ft^2)
Q_{conv}	Heat in convective zone, (btu/lb)
Q_{rac}	Heat radiant absorbed calculated (lb/hr)
T_i	Inlet process stream temperature (^oF)
T_o	Outlet process stream temperature (^oF)
T_t	Tube wall temperature (^oF)
T_{LO}	Outlet temperature (^oF)
T_{LI}	Inlet temperature (^oF)
T_S	Stack temperature (^oF) T_{LI}
T_{SA}	Stack approach temperature (^oF)
Uc	Overall heat transfer coefficient (btu/hr ft^2)
$V_{furnace}$	Furnace volume (ft^3)
W	Shell wide (ft)
Xair	Fraction excess air

Greek Leters

Φ	Gas emissivity
αA_r	Effective absortivity (ft^2)
ρ	Density (lb/ft^3)

Superscript

M	Mass molecular